

MEMORANDUM
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AN ANNOTATED BIBLIOGRAPHY OF DYNAMIC CLOUD MODELING: SUPPLEMENT

F. W. Murray

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PREFACE

In March 1968 RAND published An Annotated Bibliography of Dynamic Cloud Modeling, RM-5582-ESSA, which contained about 120 entries from the world literature on the subject. The interest with which the Bibliography was received, together with RAND's continuing concern in numerical cloud modeling, especially as it relates to weather modification, led to efforts to keep the Bibliography current. Since publication of the original Bibliography, sufficient new papers have appeared and old ones have been brought to our attention to warrant the publication of this supplement. It is expected that, from time to time in the future, additional supplements will be forthcoming, and perhaps a new edition of the Bibliography may eventually be justified.

AN ANNOTATED BIBLIOGRAPHY OF DYNAMIC

CLOUD MODELING: SUPPLEMENT

Alberty, Ronnie Lee: Dynamic Pressure Effects in Organized Convection.

Ph.D. Dissertation, The University of Missouri, Columbia, Missouri, 1967, 76 pp.

Two methods are given for determining dynamic pressure in a convective situation, both based on potential flow about the convective column, considered as an obstacle. Vertical shear in the environment is taken into account, and the results are applied to a cumulonimbus. It is shown that, under some circumstances, vertical dynamic pressure gradients augment existing vertical motion fields in a manner with positive feedback, so that in a short time the quasi-steady-state severe storm stage can be reached.

Amirov, A. D.: "The Effect of an Artificial Heat Source Upon the Development of a Cumulus Cloud. A Numerical Experiment."

IN RUSSIAN: Izvestiya Akademii Nauk SSSR, Fizika Atmosfery i Okeana, Vol. 4, 1968, pp. 152-159.

IN ENGLISH: Bulletin of the Academy of Science USSR, Atmospheric and Oceanic Physics, Vol. 4, 1968, (Published by the American Geophysical Union), pp. 85-89.

This is a numerical model of a cumulus cloud in cylindrical coordinates, with condensation and a parameterization of gravitational displacement of liquid water. The turbulence coefficient is a variable proportional to velocity gradient. For a given steady heat source the cloud eventually reaches a quasi-steady state. If the heat source is removed, the cloud decays.

Arnason, Geirmundur, Richard S. Greenfield, and Edward A. Newburg: "A Numerical Experiment in Dry and Moist Convection Including the Rain State."

Journal of the Atmospheric Sciences, Vol. 25, 1968, pp. 404-415.

The dynamic equations with rectilinear symmetry are solved numerically for (1) dry convection in a statically neutral atmosphere, (2) moist convection in a saturated atmosphere. Precipitation is parameterized. Although, as in other similar models, pressure does not appear explicitly in the dynamic equations, it is computed through a balance equation and found to differ markedly from the hydrostatic pressure. It acts in a manner similar to form drag on a body moving through a viscous fluid.

Barcilon, Albert I.: "Phase Space Solution of Buoyant Jets."

Journal of the Atmospheric Sciences, Vol 25, 1968, pp. 796-807.

The steady flow field in a turbulent jet moving in stagnant surroundings is considered. The coordinates used are integral with height of mass flux, mass flux, and derivative with height of mass flux; a method is given to relate this phase space solution to physical space. Solutions are given for neutral and stably stratified surroundings.

Barnes, Stanley Louis; Effects of Large-scale Subsidence on Cellular Convection in the Atmosphere: A Numerical Experiment.

Ph.D. Dissertation, The University of Oklahoma, Norman, Oklahoma, 1967, 109 pp.

The problem of weak cellular convection (analogous to Bénard convection) as observed by satellite is studied by means of perturbation solutions of the linearized Boussinesq equation. The equations are reduced to two dimensions (a vertical plane). Condensation is not considered. It is found that a gradual general subsidence is necessary to offset the corroding effects of the convective elements. Convective perturbations of 10 to 20 km horizontal scale were amplified at first, but soon reached a steady state. Subsidence aids the growth of the perturbation at first, but later inhibits it.

Calder, K. L.: "In Clarification of the Equations of Shallow-layer Thermal Convection for a Compressible Fluid Based on the Boussinesq Approximation

Quarterly Journal of the Royal Meteorological Society, Vol. 94, 1968, pp. 88-92.

The Boussinesq equation of motion, continuity, and energy are briefly derived in a manner similar to that of Spiegel and Veronis (1960). It is found that the fluctuations may be referred to any polytropic equilibrium atmosphere that meets certain conditions on the size of the departures from an atmosphere with constant lapse rate. The adiabatic lapse rate is derived on the basis of the equations of shallow-layer thermal convection.

Dalley, A. C.: "On the Computer Calculation of Vapor Pressure and Specific Humidity Gradients from Psychrometric Data."

Journal of Applied Meteorology, Vol. 7, 1968, pp. 717-719.

It is shown that the rate of change of saturation vapor pressure with respect to temperature can be determined satisfactorily by differentiation of Tetens' formula. An expression is given for this quantity, and also a simplified expression is given for the gradient of specific humidity. Error tables are shown to justify the approximations.

Fraser, A. B.: "The White Box: The Mean Mechanics of the Cumulus Cycle "

Quarterly Journal of the Royal Meteorological Society, Vol. 94, 1968, pp. 71-87.

The "white box" associated with and containing a particular cumulus cloud is defined as the air above cloud base that has been moistened by the cloud but has not come into hydrostatic equilibrium with the environment. It contains all the air "processed" by the cloud, and no sensible heat can be transported across its boundaries. It is found that, for a non-precipitating cloud the horizontal temperature profile reaches a minimum at the visible edge of the cloud, and within the white box there is a net downward transport associated with the upper half of the cloud. Thus there is a compensating ascent in the upper part of the environment and descent in the lower part. This type of convection can either stabilize or destabilize the environment.

Fujita, Tetsuya, and Hector Grandoso: "Split of a Thunderstorm into Anticyclonic and Cyclonic Storms and their Motion as Determined from Numerical Model Experiments."

Journal of the Atmospheric Sciences, Vol. 25, 1968, pp. 416-439.

A cumulonimbus is modeled as a rotating core of undiluted air with vertical velocity uniform in the horizontal surrounded by a rotating annulus of air in which entrainment occurs. In order to account for vertical shear in the embedding current, the undiluted core is divided into a number of discs, and the forces on each disc are calculated. Clouds deviate to the left or right of the embedding flow depending on whether they rotate anticyclonically or cyclonically, and the amount of deviation depends on speed of rotation, but not in a simple way. A split pair with equal and opposite rotations is modeled, and results are compared with observations.

Goldman, Joseph L.: "The High Speed Updraft - The Key to the Severe Thunderstorm."

Journal of the Atmospheric Sciences, Vol. 25, 1968, pp. 222-248.

A steady-state thunderstorm is modeled in terms of five layers of specified depth: (1) moist inflow near the ground (translation plus a sink), (2) dry inflow (translation plus a sink), (3) cold outflow just below the cloud base (translation plus a source), (4) barrier flow layer at the "throat" of the cloud (horizontal flow past a cylinder), and (5) outflow at the top of the storm (translation plus a source). A functional form is prescribed for the vertical component of velocity, and the flow is described in complex potential notation. Precipitation is treated after the manner of Kessler (1959, 1961). Some features of the model are found to agree well with observations. The model is formulated so as to permit evolutionary improvements.

Krishnamurti, T. N.: "A Calculation of Percentage Area Covered by Convective Clouds from Moisture Convergence."

Journal of Applied Meteorology, Vol. 7, 1968, pp. 184-195.

The total moisture convergence over an area of synoptic scale is used to determine what fraction of the area will be covered by active convective cloud elements. In a particular case comprising an easterly wave over the Caribbean this is determined to be near one percent, which is in reasonable agreement with observations made by airborne radar.

Lebedev, S. L.: "On the Questions of Influence of Gravitational Settling of Cloud Drops on the Water Content of Clouds."

IN RUSSIAN: Izvestiya Akademii Nauk SSSR, Seriya Geofyzicheskaya, No. 11, 1963, pp. 1741-1746.

IN ENGLISH: Bulletin of the Academy of Science USSR, Geophysics Series, No. 11, 1963 (published by the American Geophysical Union), pp. 1053-1056.

A parameterized method for computing the fall-out of water from a cloud is developed. A weighted mean settling velocity is defined; it depends on the liquid water content and the drop-size distribution function. An empirical expression is developed for the variation of mean settling function with liquid water content, and the Khrgian-Mazin distribution function is assumed. This formulation can be used in connection with numerical cloud models.

Lebedev, S. L.: "Calculating the Processes Due to the Entry of Ice Crystals into Supercooled Droplet Clouds."

IN RUSSIAN: Doklady Akademii Nauk SSSR, Vol. 164, 1965, pp. 796-799.

IN ENGLISH: Doklady of the Academy of Science USSR, Earth Sciences Sections, Vol. 164, 1965, (published by the American Geological Institute), pp. 15-17.

A system of equations is derived to determine (1) mass of vapor condensing on drops, (2) mass of vapor deposited on ice crystals, (3) mass of water in drops settling on ice crystals and freezing, (4) change in mass of ice due to gravitational fall of crystals, (5) change in number of drops on coagulation with crystals, (6) change in number of crystals due to gravitational fall, and (7) number of crystals produced by seeding. The size distribution of both drops and crystals is assumed to be that of Khrgian and Mazin.

Leblanc, Lynn L.: A Numerical Experiment in Predicting Stratus Clouds

Ph.D. Dissertation, Texas A & M University, College Station, 1967, 123 pp.

A hydrostatic two-dimensional model is derived to simulate the formation of stratus clouds over the Texas coastal plain. Incompressible flow is assumed, and turbulent transfer of heat, moisture, and momentum (in the vertical direction) are included. The grid is a vertical plane perpendicular to the coast line. The driving mechanism is the nocturnal surface cooling. When a sloping lower boundary is assumed, stratus forms 4 hours after initial time in qualitative agreement with observations, but with a flat lower boundary no stratus forms. Three formulations for the turbulent exchange coefficients are tested.

Lilly, Douglas K.: "Theoretical Models of Convection Elements and Ensembles."

Advances in Numerical Weather Prediction, 1965-66, Seminar Series, Travelers Research Center, Inc., Hartford, Connecticut, 1966, pp. 24-33.

This paper briefly surveys recent work in dynamical cloud modeling. Part I is devoted to laboratory experiments and analytical theory, and it gives some characteristics of several plume and bubble models. Part II is devoted to numerical solutions. Considerable attention is paid to problems of turbulence and eddy diffusion, and the conclusion is reached that only a three-dimensional model will be satisfactory. Methods of treating cloud physics interactions are discussed briefly.

Lilly, D. K.: "Models of Cloud-topped Mixed Layers under a Strong Inversion."

Quarterly Journal of the Royal Meteorological Society, Vol. 94, 1968, pp. 292-309.

Theoretical models of a radiatively active turbulent cloud layer over the sea and under a strong subsidence inversion are constructed. One model considers a dry aerosol cloud; the other considers a water cloud with latent heat exchanges. It is found in the latter case that wet-bulb potential temperature must increase upward in the inversion. Steady-state solutions are found with results that agree with observations in California, where this situation is common. The model also offers a partial explanation of the origin of the trade-wind inversion.

McCarthy, John: "Computer Model Comparisons of Seeded and Not-seeded Convective Cloud Depth Using Project Whitetop Data."

Proceedings of the First National Conference on Weather Modification, Albany, New York, 28 April - 1 May, 1968, pp. 270-279.

The model of Simpson, Simpson, Andrews, and Eaton (1965) is used to study the effect of seeding on summertime cumulus convection over Missouri. A set of atmospheric soundings appropriate to the time and place was used with a variety of glaciation levels. It was found that seedability decreases as the level of natural glaciation becomes warmer, and that greatest seedability comes with a lapse rate of 7 to 8 degree km^{-1} . The problem of defining the correct cloud radius was difficult.

Molenkamp, Charles R.: "Accuracy of Finite Difference Methods Applied to the Advection Equation."

Journal of Applied Meteorology, Vol. 7, 1968, pp. 160-167.

Several finite-difference schemes (including the upstream, the leapfrog, and the Arakawa methods) are tested on a case with known analytic solution. Although the study was done in the context of cumulus simulation, the results are general. It is found that simple schemes introduce a pseudo-diffusive effect. The most accurate method was found to be that of Roberts and Weiss, but it requires 4 times as many grid points and 45 times as much computation time as the upstream method.

Orville, Harold D.: "Ambient Wind Effects on the Initiation and Development of Cumulus Clouds over Mountains."

Journal of the Atmospheric Sciences, Vol. 25, 1968, pp. 385-403.

This paper contains essentially the same material as an earlier contract report by Orville (1967). Principal observations and conclusions are: (1) Vertical shear stimulates cloud initiation but damps further cloud development. (2) There are two kinds of cloud development with ambient wind -- slow growth in one position with life cycle of 40 minutes and fast development with the cloud moving downwind. (3) With ambient wind and a heated, moist ridge, wave motion is caused upwind of the ridge. (4) Stable regions form in the upper levels, the effect probably being enhanced by the 2-dimensionality of the model. (5) Downslope motion is eventually established over the downwind slope. (6) Cool cores can form. (7) Superadiabatic layers over the plains and the ridge develop.

Panchev, St., and V. Andreyev: "Nonadiabatic Rise of Individual Volumes of Air in a Stably Stratified Atmosphere."

IN RUSSIAN: Izvestiya Akademii Nauk SSSR, Fizika Atmosfery i Okeana, Vol. 4, 1968, pp. 215-219.

IN ENGLISH: Bulletin of the Academy of Science USSR, Atmospheric and Oceanic Physics, Vol. 4, 1968, (published by the American Geophysical Union) pp. 121-124.

The rise of a warm bubble with constant entrainment rate is considered. Cases are considered with constant lapse rate and with low-level inversion. Convection height and maximum velocity of ascent are considered.

Pedley, T. J.: "Similarity Solutions for Turbulent Jets and Plumes in a Rotating Fluid."

Journal of the Atmospheric Sciences, Vol. 25, 1968, pp. 789-795.

Similarity solutions are derived for a turbulent jet (constant momentum flux) and a turbulent plume (constant buoyancy flux) directed along the axis of a fluid in solid rotation with small Rossby number. It is not yet determined whether the solutions represent experimentally realizable flows.

Simpson, Joanne, Victor Wiggert, and Thomas R. Mee: "Models of Seeding Experiments on Supercooled and Warm Cumulus Clouds."

Proceedings of the First National Conference on Weather Modification, Albany, New York, 28 April - 1 May 1968, pp. 251-269.

A model is described that involves integrating a differential equation for the vertical acceleration of a cumulus tower, where the acceleration is formulated as the difference between a buoyancy term and a drag term. The equation is that of Turner's (1962) starting plume. A quasi-Lagrangian scheme is used so that the value of a variable for a height Z represents the property of the cloud as it passes through that height. Results are strongly controlled by the entrainment law, in which entrainment is inversely proportional to cloud radius. Horizontal structure of the cloud is not considered. Kessler's (1965) precipitation mechanism is used. Tests of the model against field experiments are described.

Weinstein, A. L., and L. G. Davis: A Parameterized Numerical Model of Cumulus Convection.

Report No. 11 to the National Science Foundation, NSF GA-777. Department of Meteorology, The Pennsylvania State University, 1968, 44 and 22 pp.

This report describes a one-dimensional, steady-state numerical model of a convective cell in which the various physical processes have been parameterized. Input consists of a vertical sounding of pressure, temperature, humidity, and horizontal wind speed plus height of cloud base, vertical velocity and radius of cloud at cloud base, and several physical parameters. A bubble is allowed to ascend one grid unit at a time, and successive corrections are made to temperature and mixing ratio for moist adiabatic ascent, entrainment, and evaporation. Freezing occurs at the ice nucleation temperature. Liquid water is divided into two categories -- cloud water and hydrometeor water -- after the manner of Kessler (1967). However, since the method of calculation prevents consideration of fall-out, hydrometeor water is arbitrarily reduced at intervals. Vertical wind is computed. Hydrostatic equilibrium is assumed for thermo-dynamic computations, but in the dynamics an equation for vertical acceleration similar to that of the Boussinesq system is derived. Usages of the model in connection with field experimentation are suggested.

Vul'fson, N. I.: "Effect of Air Humidity on Development of Convection in a Cloudless Atmosphere."

IN RUSSIAN: Doklady Akademii Nauk SSSR, Vol. 151, 1963, pp. 1089-1092.

IN ENGLISH: Doklady of the Academy of Sciences USSR, Earth Sciences Sections, Vol. 151, 1963 (published by the American Geological Institute), pp. 10-12.

It is shown from the equations of hydrodynamics that ascending currents can be initiated by horizontal gradients of humidity when the temperature is uniform in the horizontal. Measurements made by instrumented aircraft over the Black Sea substantiate this. It is argued that this is the principal mechanism for convection operating over the sea in the daytime.

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10. ABSTRACT A bibliography of material dealing with numerical cloud models, experiments, and methodology. It covers the period from March to November 1968 and contains twenty-four entries. Some Russian-language publications are included. This Memorandum is a supplement to RM-5582-ESSA.		11. KEY WORDS Bibliography Models Clouds Meteorology Computer simulation	